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# Water Quality Assessment for the Proposed Water Supply Reservoir, Duck River, Cullman, Alabama

*by Steven L. Ashby, Robert H. Kennedy*

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Prepared for U.S. Army Engineer District, Nashville
U.S. Army Engineer District, Mobile

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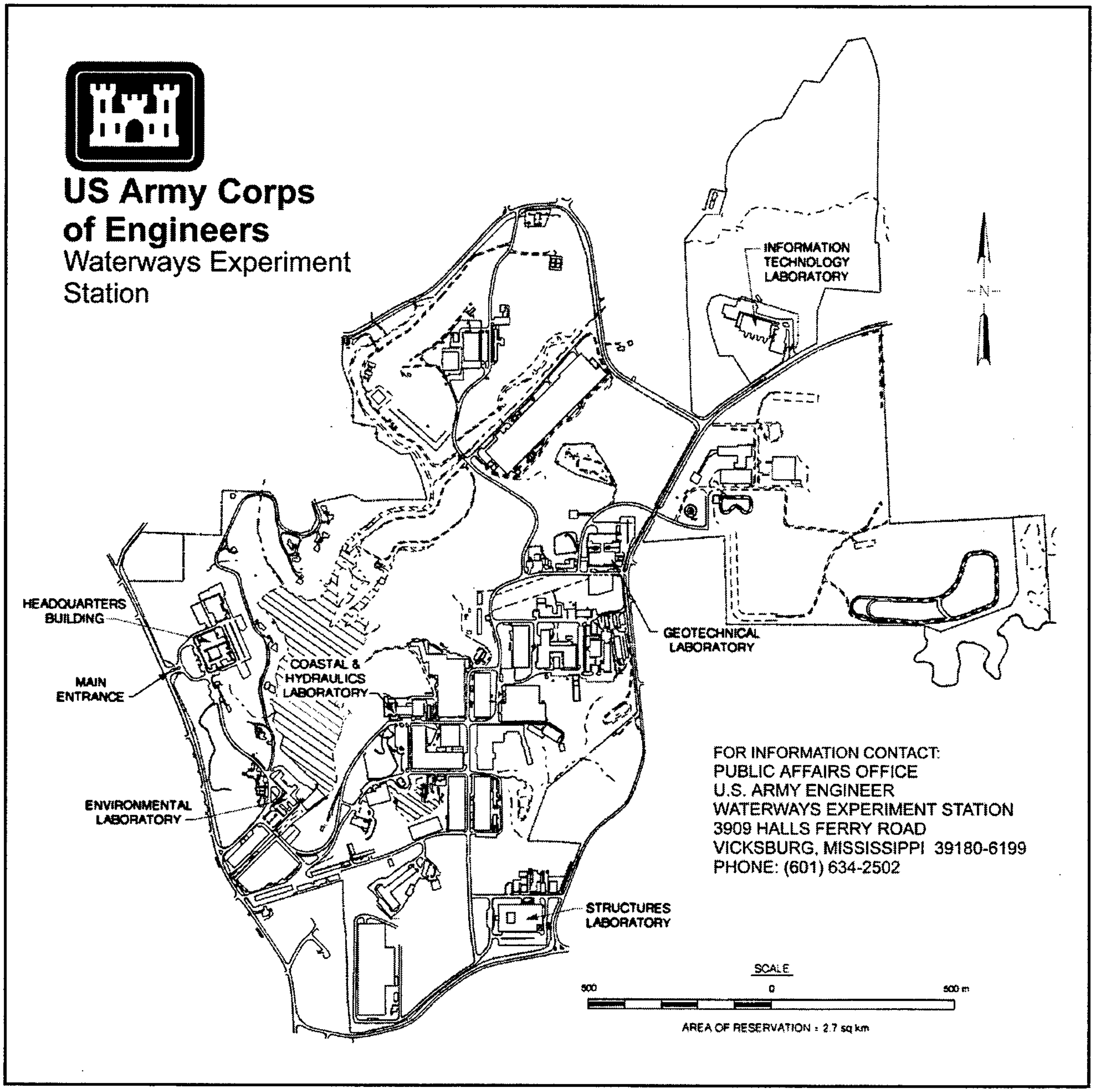


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# Preface

A study using BATHTUB, an empirical model that predicts chlorophyll and transparency values, was conducted to assess the potential for water quality problems for a proposed water supply reservoir on the Duck River near Cullman, AL. The study was conducted for the U.S Army Engineer District, Nashville, and the U.S. Army Engineer District, Mobile, by the Environmental Laboratory (EL), U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, a complex of five laboratories of the Engineer Research and Development Center (ERDC).

This report was prepared by Mr. Steven L. Ashby and Dr. Robert H. Kennedy, Ecosystem Processes and Effects Branch, Ecosystem Processes and Effects Division, EL. The work was conducted under the direct supervision of Dr. Richard E. Price, Chief, Ecosystem Processes and Effects Division; and under the general supervision of Dr. John W. Keeley, Acting Director, EL.

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# 1 Introduction

## Background

Enrichment of lakes with nutrients, organic matter, and sediment is a natural, long-term process referred to as eutrophication. This process often results in decreased water clarity, excessive algal production, reduced dissolved oxygen concentrations in bottom waters during stratified periods, and decreased volume. This process is greatly accelerated for lakes that are impacted by human activity in the watershed. Since reservoirs typically have relatively large and often extensively developed watersheds, they receive elevated loads of nutrients and sediment and are, therefore, highly susceptible to accelerated eutrophication (Kennedy, Thornton, and Ford 1985).

Water quality studies conducted by TTL, Inc. and the Alabama Department of Environmental Management (ADEM) indicated that the proposed reservoir on the Duck River in Alabama has a potential for water quality problems associated with eutrophication. Excessive nutrients from the watershed were considered to be the source of the problems and a watershed management plan is in preparation to address the potential water quality problem and to develop control measures to reduce the nutrient loading to the proposed reservoir.

An assessment of potential water quality of the proposed reservoir associated with varied nutrient loading estimates from existing data and potential changes in nutrient loading associated with implementation of best management practices (BMPs) is required for the watershed management plan and environmental assessment of the proposed project. The empirical model, BATHTUB, developed for the U.S. Army Corps of Engineers Waterways Experiment Station by Walker (1996) was selected to make this assessment. Although based on theoretical concepts, such as mass balance and nutrient limitation of algal growth, the model does not attempt to simulate explicitly the dynamics of a reservoir in either time or space. Instead, BATHTUB produces spatially and temporally averaged estimates of reservoir water quality conditions.

BATHTUB, developed from a Corps of Engineers database, models water quality conditions in a two-stage procedure involving two model types. First, nutrient concentrations are estimated based on nutrient loads, morphometry, and hydrology. Second, a eutrophication response model is executed to relate

reservoir nutrient concentrations to chlorophyll concentrations and transparency. These models produce estimates of steady-state, long-term (growing season or annual), water quality conditions in the epilimnion and are not intended to predict or describe short-term, event-related dynamics in reservoirs or to generate vertical profiles of water quality conditions. Details of the development, assumptions, and use of BATHTUB can be found in Walker (1981, 1982, 1985, 1987, 1996).

## Purpose

The objective of the study is to provide predictions of selected water quality constituents (phosphorus and nitrogen species) and response variables (chlorophyll *a* and water transparency as measured by Secchi disk depth) under different nutrient loading scenarios that considered both external and internal nutrient sources as well as the effects of reduced nutrient loadings that would result from implementation of BMPs.

# 2 Project Description

The proposed water supply reservoir will be located on the Duck River in northeastern Alabama. Pertinent project features include watershed and land use information, anticipated inflow hydrology and material loading, and reservoir operations. The watershed covers approximately 23,347 acres or 94.49 $km^2$ and is heavily used for agricultural activities including 173 poultry houses and three dairy operations. Details of the watershed and land use are more fully presented in the draft of the Cullman-Morgan Water District Duck River Water Supply Project - Watershed Management Plan (Almon Associates, Inc., 1999).

The Duck River and its tributaries have not been gaged, so little information exists on the hydrology of the watershed. A newly established gage at the site of the proposed dam has not yet been rated, so data are limited to stage heights. Inflow hydrology has been evaluated with numerical modeling using a modified version of HEC1 to simulate discharge for a range of runoff events (U.S. Army Corps Engineers et al., 1998). Runoff from the watershed adjacent to the west has also been evaluated for 5,400 agricultural acres using an agricultural runoff model, Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) (Natural Resource Conservation Service 1995). The average annual discharge at the proposed dam is estimated to be near 53 $ft^3\ sec^{-1}$.

The proposed project includes a zoned rockfill embankment with a thin impervious core, a pump station with a maximum rate of 32 Million Gallons per Day (MGD) and a multilevel intake tower. The project is expected to supply 6 to 12 MGD of the current and projected water supply needs (22 to 31 MGD) after construction. The project will add to the existing water supply (Catoma Lake) and be used as a reserve supply. The projected operation to provide 18 MGD, estimated as average demand, will initially use 6 MGD (9.28 $ft^3\ sec^{-1}$) from the Cullman/Morgan water supply. An increase of 0.6 to 1 MGD is estimated for each year. Leakage from the dam is expected to provide 5-6 $ft^3\ sec^{-1}$. A minimum flow regime will be maintained with releases through the intake tower. The intake tower will allow selective withdrawal capabilities but reservoir elevations and discharge guidelines have not been determined. The area/capacity curve is presented in Figure 1 and selected reservoir hydrologic information is presented in Table 1.

**Table 1**
**Reservoir Hydrologic and Morphometric Data for Selected Elevations**

| Elevation (ft) | Area (ac) | Volume (acft) | Mean Depth (m) |
|---|---|---|---|
| 690 | 260 | 6,250 | 7.3 |
| 710 | 450 | 13,250 | 9.0 |
| 720 | 560 | 18,500 | 10.1 |
| 730 | 700 | 25,000 | 10.9 |

# 3 Data Sources and Discussion

## Hydrology

HEC1 results (U.S. Army Corps of Engineers 1998), flow data from nearby USGS gaging stations, and field measurements of flow provided by ADEM and TTL, Inc. field studies were reviewed and compared with surface water runoff and precipitation information provided by Geraghty et al. (1973). Although several scenarios were evaluated with HEC1, a curve number (CN) of 80 was considered to provide the best estimate and compares to a CN of 72 used in the GLEAMS model.

Average estimates of precipitation (53 in), surface-water runoff (20-30 $ft^3$ $sec^{-1}$), and normal distributions of surface-water runoff provided in Geraghty et al. (1973), yielded an expected annual average discharge of 53 $ft^3$ $sec^{-1}$. These figures were comparable to estimates provided in Almon Associates (1999) who reported an average rainfall of approximately 56 inches per year for the project area and an average annual discharge at the dam site of 52.8 $ft^3$ $sec^{-1}$. This may be an under estimate of average inflow since the average of 12 drought years between 1927 and 1996 (U.S. Army Corps of Engineers 1998) was 50.7 inches.

Limited discharge data were available, except for instantaneous flow measurements conducted during water quality sampling in 1997 and 1998. Evaluation of USGS gage data from nearby gaging stations was also conducted. While most of the runoff occurs between late February and early April, considerable events in June and August occurred at nearby gage stations indicating that summer storm events and increased runoff are likely. Two observations of flow in June and July of 1988 near 0 and 1.6 $ft^3$ $sec^{-1}$ indicate that very low to immeasurable flows can also occur during the summer of dry years. Consequently, inflows during the summer growing season are anticipated to range between 10 and 50 $ft^3$ $sec^{-1}$ except during storm events when runoff would be higher. Additional hydrologic information is summarized in Table 2.

**Table 2**
**Watershed Hydrology and Retention Times for Selected Elevations**

| Flow ($ft^3\ sec^{-1}$) | Runoff ($m\ yr^{-1}$)[1] | Retention Time (yrs)[2] |
|---|---|---|
| 10 | 0.09 | 2.9 |
| 25 | 0.24 | 1.16 |
| .50[3] | 0.47 | 0.58 |
| 75 | 0.71 | 0.39 |
| 100 | 0.89 | 0.29 |

[1] Drainage Area = 94.49 $km^2$
[2] Reservoir Elevation = 725 ft
[3] Computed from Runoff and Precipitation Data from Geraghty et al. 1973.

## Water Quality

Water quality data were compiled from the Environmental Protection Agency (EPA) Storage and Retrieval System (STORET), the EPA National Eutrophication Survey (NES) data base, and field studies conducted by ADEM and TTL, Inc. Station locations are depicted in Figure 2. The STORET retrieval was conducted by retrieving surface water quality data from the hydrologic unit (03160109) and then retaining only pertinent parameters. Data from ADEM and TTL, Inc. were not included in the STORET retrieval. Stations in the STORET retrieval were reviewed by latitude and longitude and station descriptions. Data from the Duck River were not present in the STORET retrieval. The STORET data were compiled for a sub-ecoregion and were primarily from Mud Creek.

Data from the NES data base for area lakes (Table 3) were evaluated and loading rates were used to calculate average concentrations which were then compared to average values from STORET and field data described below (Table 4). The NES data represents an average for the entire watershed and do not reflect runoff values for different land uses. Average values of 50.4 $\mu g\ l^{-1}$ for total phosphorus and 979.1 $\mu g\ l^{-1}$ for total Kjeldahl nitrogen were considered to be representative of expected average runoff concentrations.

Water quality data provided by ADEM included observations from 1988, 1991, and 1997. These data were not included in the retrieval from STORET. Data were collected at stations Duck Creek 01 through 04 monthly from April through October in 1988. Two stations were sampled once a month from June through October in 1991. In 1997, 6 stations on Duck Creek and 3 stations on Thacker Creek were sampled once a month from May through October.

**Table 3**
**Material Loading Estimates from the NES Data Base**

| Lake | State | Flow ($m^3$ $sec^{-1}$) | P_NPS (kg $yr^{-1}$) | TP ($\mu g$ $l^{-1}$) | N_NPS (kg $yr^{-1}$) | TN ($\mu g$ $l^{-1}$) |
|---|---|---|---|---|---|---|
| Bankhead | AL | 179.8 | 192450 | 33.9 | 5518865 | 973.3 |
| Guntersville | AL | 1,097.7 | 1794225 | 51.8 | 35129790 | 1,014.8 |
| Lay | AL | 343.8 | 831070 | 76.7 | 13881440 | 1,280.3 |
| Mitchell | AL | 434.5 | 1079840 | 78.8 | 13010680 | 949.5 |
| Purdy | AL | 2.33 | 6545 | 89.1 | 57125 | 777.4 |
| Weiss | AL | 234.4 | 900555 | 121.8 | 8425585 | 1,139.8 |
| Beaver | AR | 42.4 | 36140 | 27 | 1448335 | 1,081.9 |
| Allatoona | GA | 50.6 | 72755 | 45.6 | 982730 | 615.9 |
| **Average** | | | | **65.6** | | **979.1** |
| | | | | **50.4**[1] | | |

1 Recalculated excluding TP value from Weiss Lake.

Water quality data provided by TTL, Inc. included data from eleven stations that were sampled once a month in November of 1997 and January, February, May, and August of 1998. Four stations were considered to be the same as 4 ADEM stations (TTL2=DCK2, TTL4=DCK6, TTL5=DCK3, TTL6=DCK4).

Data from the above sources are presented for total phosphorus and total Kjeldahl nitrogen (Figure 3). In general, the NES value fell within the range of values observed for all sites except Mud Creek, which was consistently higher except for the winter, high flow event. The Mud Creek watershed contains a point source for nutrients at the Hanceville wastewater treatment plant. Elevated nutrient concentrations observed in 1988 may be attributed to poor conditions at the treatment plant when these samples were collected. Lower concentrations observed in 1991 suggest that conditions have improved since 1988. The Duck River watershed does not have a point source pollution issue.

**Table 4**
**Summary of Water Quality Data from STORET, ADEM, and TTL, Inc.**

| Data Source | | Year | Parameter | Param. Code | Min | Max | Mean |
|---|---|---|---|---|---|---|---|
| STORET | 21AWIC-MUD CREEK | 88-89 | Residue, T nonfilterable | 530 | 3 | 72 | 24.3 |
| | | | T. Organic Carbon | 605 | 0.2 | 6.9 | 1.9 |
| | | | T. Nitrate N | 620 | 0.04 | 4.02 | 0.89 |
| | | | T. Kjeldahl N | 625 | 0.4 | 18.1 | 5.53 |
| | | | Ammonia Unionized | 612 | 0.2 | 11.2 | 3.62 |
| | 21AWIC-MUD CREEK | 77-78 | Nitrogen (mg $l^{-1}$) | 610 | 1 | 4.5 | 1.85 |
| | | | Nitrite N (mg $l^{-1}$) | 615 | 0.02 | 10.5 | 0.8 |
| | | | T. Nitrate N (mg $l^{-1}$) | 620 | 0.33 | 2.3 | 1.07 |
| | | | T. Kjeldahl N (mg $l^{-1}$) | 625 | 1 | 5.9 | 2.37 |
| | | | T. Phosphorus (mg $l^{-1}$) | 665 | 0.05 | 1.3 | 0.256 |
| | 112WRD-34103208 | 11/77,1/78, 8-11/78 | Ammonia N (mg $l^{-1}$) | 608 | 0.05 | 2.4 | 0.535 |
| | | | Nitrate N, Diss. (mg $l^{-1}$) | 618 | 0.05 | 1.2 | 0.35 |
| | | | Dissolved P (mg $l^{-1}$) | 666 | 0 | 0.88 | 0.044 |
| | | | Diss. Ortho-P (mg $l^{-1}$) | 671 | 0.06 | 0.48 | 0.072 |
| | 112WRD-2450000 | 72-82 | Nitrate N, Diss. (mg $l^{-1}$) | 618 | 0.01 | 1.8 | 0.92 |
| ADEM | | 1988 | Flow ($ft^3$ $sec^{-1}$) | 61 | 0 | 453 | |
| | | | Turbidity (JTU) | 70 | 1.4 | 13 | 4.8 |
| | | | D.O. (mg $l^{-1}$) | 300 | 2.4 | 9.8 | 6.8 |
| | | | BOD5 (mg $l^{-1}$) | 310 | 1 | 3 | 1.4 |
| | | | pH (SU) | 400 | 5.7 | 7.3 | 6.4 |
| | | | Residue T.NFil (mg $l^{-1}$) | 530 | 1 | 26 | 6.7 |
| | | | Organic N (mg $l^{-1}$) | 605 | 0.4 | 1.7 | 1 |
| | | | Ammonia N (mg $l^{-1}$) | 610 | 0.1 | 1 | 0.19 |
| | | | TKN (mg $l^{-1}$) | 625 | 0.4 | 1.8 | 1.07 |
| | | | Nitrate/Nitrite N (mg $l^{-1}$) | 630 | 0.02 | 2.06 | 0.92 |
| | | | Tot. P (mg $l^{-1}$) | 665 | 0.01 | 0.09 | 0.03 |
| ADEM | | 1991 | D.O. (mg $l^{-1}$) | | 2.6 | 8.6 | 5.2 |
| | | | BOD5 (mg $l^{-1}$) | | 0.4 | 8.1 | 1.8 |
| | | | pH (SU) | | 5.8 | 8.6 | 7.3 |
| | | | Ammonia N (mg $l^{-1}$) | | 0 | 0.15 | 0.05 |
| | | | TKN (mg $l^{-1}$) | | 0.03 | 0.56 | 0.4 |
| | | | Nitrate/Nitrite N (mg $l^{-1}$) | | 0.05 | 1.1 | 0.46 |
| | | | Tot. PO4 (mg $l^{-1}$) | | 0.02 | 0.12 | 0.05 |
| ADEM | | 1997 | Tot. P (mg $l^{-1}$) | | 0.018 | 0.359 | 0.095 |
| | | | Sol. Reac. P (mg $l^{-1}$) | | 0.005 | 0.069 | 0.021 |
| | | | TKN (mg $l^{-1}$) | | 0.015 | 3.163 | 0.567 |
| | | | NH3N (mg $l^{-1}$) | | 0.005 | 0.121 | 0.04 |
| TTL | | 1998 | Tot. P (mg $l^{-1}$) | | 0.05 | 0.13 | 0.073 |
| | | | Sol. Reac. P (mg $l^{-1}$) | | 0.05 | 0.08 | 0.052 |
| | | | TKN (mg $l^{-1}$) | | 0.2 | 3.72 | 0.536 |
| | | | NH3N (mg $l^{-1}$) | | 0.1 | 0.67 | 0.187 |

# 4 Model Application

Nutrient input concentrations were taken from average NES values for total phosphorus and nitrogen (50 and 980 $\mu g\ l^{-1}$, respectively) and the model was applied with these values as runoff concentrations for a single land use. Fixed values provided by Walker (1996) were used in the second order model (model 3) for both phosphorus (0.1) and nitrogen (0.00315). Internal loading of nutrients was developed with data from a variety of sources (Table 5). A rate of 2 mg $m^{-2}$ $day^{-1}$ was considered to be representative for internal loading of phosphorus to the epilimnion and a rate of 20 mg $m^{-2}$ $day^{-1}$ was used for nitrogen.

**Table 5**
**Internal Nutrient Loading Rates**

| Phosphorus (mg $m^{-2}$ $day^{-1}$) | Nitrogen (mg $m^{-2}$ $day^{-1}$) | Lake Region | Lake | Reference |
|---|---|---|---|---|
| 2 - 3 | | Epilimnion | West Lake and East Lake, OH | Cooke and Kennedy 1977 |
| <0 - 10.3 | <0 - 267.8 | Epilimnion | Eau Galle Lake, WI | Gaugush 1984 |
| 3.8 | | Oxic | Lake Pepin, MN/WI | James et al. 1995 |
| 15 | | Anoxic | Lake Pepin, MN/WI | James et al. 1995 |
| 3.6 | | Littoral | Eau Galle Lake, WI | James and Barko 1991b |
| 0.2 - 1.8 | | Littoral | Eau Galle Lake, WI | James and Barko 1991a |
| 4.7 - 6.0 | | Lakewide | Cameron Lake, Ontario | Dillon 1975 |
| **2 (estimated)** | **20 (estimated)** | **Epilimnion** | **Proposed Lake** | |

Non-algal turbidity was calculated with the following equation:

Non-algal turbidity ($m^{-1}$) = 1/S - 0.025 B

where S = Secchi depth (m) and B = Chlorophyll *a* concentration (mg $m^{-3}$).

A Secchi depth of 1.8 meters and a chlorophyll *a* concentration of 10 (mg $m^{-3}$) were used to calculate a non-algal turbidity value of 0.31.

Chlorophyll *a* was modeled with the P,N, Low-Turbidity model (Model 3) which was selected based on non-algal turbidity value described above. This model is appropriate when non-algal turbidity is < 0.4 $m^{-1}$ and summer flushing is < 25 $year^{-1}$. Summer flushing is a rate of water exchange in a reservoir and is calculated using (inflow – evaporation)/volume. As the rate decreases, retention times increase and settling of particulate matter increases. The net result is a decrease in non-algal turbidity.

Model: $B = CB\ 0.2\ Xpn^{1.25}$
where B = Chlorophyll *a* concentration (mg $m^{-3}$), CB = calibration factor for chlorophyll *a* (default used), Xpn = composite nutrient concentration (mg $m^{-3}$)

Since reservoir operations are currently undetermined, three scenarios were selected to describe potential changes in water quality. These three scenarios result in different retention times and allow evaluation of effects of increased internal nutrient loading. In the first scenario, hydrologic conditions for three elevations and flows were used to simulate hydrologic regimes representative of low, average, and high flow conditions (Table 6). The input file for the average runoff rate (50 $ft^3\ sec^{-1}$) and different reservoir elevations (Scenario 1) is included as Appendix A.

**Table 6**
**Operational Conditions Selected for Scenario 1**

| Reservoir Elevation (ft) | Inflow Rate ($ft^3\ sec^{-1}$) | Hydrologic Regime |
|---|---|---|
| 690 | 10 | Low Flow |
| 720 | 50 | Average |
| 730 | 100 | High Flow |

The second scenario holds the inflow at 50 $ft^3\ sec^{-1}$ as a baseline and predicts lake response as a function of reservoir elevation. Elevations of 690, 710, and 730 ft were selected for the second scenario.

In the third scenario, potential changes in water quality associated with reductions in nutrient loadings from implementation of the watershed management plan and best management practices were evaluated. Total phosphorus and total nitrogen concentrations were decreased by 10%, 25%, and 60% for a 50 $ft^3\ sec^{-1}$ inflow at elevations of 690, 710, 720, and 730 ft.

# 5 Results and Discussion

## Scenario 1

Predicted concentrations of total phosphorus and nitrogen for low, average, and high hydrologic regimes are relatively similar for each constituent (Figure 4). Values of total phosphorus were near 35 $\mu g\ l^{-1}$ and total nitrogen values were 650 to 700 $\mu g\ l^{-1}$. Chlorophyll *a* concentrations, near 12 $\mu g\ l^{-1}$, and transparency values, near 1.6 m, were also similar across hydrologic regimes (Figure 5).

## Scenario 2

When a constant flow of 50 $ft^3\ sec^{-1}$ is input to different reservoir elevations, the residence time changes and nutrient concentrations increase at lower reservoir elevations (Figure 6). At an elevation of 690 ft, total phosphorus concentrations were predicted to be near 40 $\mu g\ l^{-1}$ and total nitrogen concentrations would exceed 800 $\mu g\ l^{-1}$. Chlorophyll *a* concentrations also increase to near 15 $\mu g\ l^{-1}$ at the lower reservoir elevations resulting in a decrease in transparency to near 1.3 m (Figure 7).

The net result of inflow rates versus reservoir elevation on chlorophyll *a* concentration is depicted in Figure 8. At lower reservoir elevations, increased loading (i.e. increased inflow) results in higher chlorophyll values while lower chlorophyll values occur at higher reservoir elevations. This assumes that internal loading of nutrients stays the same. However, the relative contribution of internal phosphorus loading is greatest for the low flow and low reservoir elevation hydrologic regime (Figure 9). Under low flow conditions, the internal loading accounted for approximately 50% of the total load while contributing approximately 30% to the total load under high flow conditions. Increased loading of phosphorus from internal sources could result in higher chlorophyll concentrations than predicted since a fixed value was used for internal phosphorus loading.

## Scenario 3

When nutrient reductions as a result of BMPs were considered, chlorophyll values decreased and Secchi values increased (Figure 10). When compared to information for other lakes in the area, chlorophyll values were still relatively higher and Secchi disk values were comparable.

# 6 Conclusions and Recommendations

The proposed project will receive a high nutrient load and will likely exhibit water quality characteristics of a mildly eutrophic system. These characteristics include high chlorophyll concentrations, which will reduce water transparency and could result in taste and odor problems if blue-green algal species occur at elevated concentrations. Increased chlorophyll production can also result in an increase in the utilization of dissolved oxygen in microbial decomposition of organic matter. If the proposed project thermally stratifies, which is likely, then isolation of bottom waters with an increased demand for dissolved oxygen will likely result in hypoxic or anoxic conditions during the summer. Decreased dissolved oxygen in the bottom waters will enhance the mobilization of reduced manganese and iron, which may affect treatment costs at the water treatment plant, and will result in an increase in the contribution of internal nutrient loading. Eutrophication is a natural process that is often accelerated with human activities and is a common occurrence in the southeastern United States. Watershed management plans and flexible reservoir operations are methods that can be utilized to minimize the acceleration of eutrophication associated with human activities.

Reductions in external sources of nutrient loads associated with the implementation of best management practices will result in improvements in water quality. Predicted changes indicate that the proposed lake would be closer, with respect to water quality, to nearby lakes if nutrient reductions of 60% can be achieved (see Figure 10).

The current plan for monitoring stream water quality using stations located at the downstream end of each sub-watershed will allow an adequate assessment of external nutrient loading to the proposed project if concentrations are correlated with flows and flows are measured frequently enough to estimate loading. The monitoring will also identify the relative contribution of each sub-watershed to the overall nutrient loading and provide guidance to the watershed management plan. Monitoring could be improved with the installation of additional stream gages and water quality sampling during runoff events, particularly in the spring and summer.

The potential importance of internal material loading (e.g., nutrients and reduced metals) increases with the extent of eutrophication and is related to operation of the system. The application of BATHTUB in this study used only one scenario for internal loading rates of nutrients. While estimated loading rates were considered representative of potential conditions, additional detail should be considered once the project is completed since fluxes from the littoral zone may also be a considerable source of internal phosphorus (James and Barko 1993). These more detailed analyses can be accomplished utilizing monitoring data from the reservoir and additional applications of the BATHTUB model.

The operation of the project will be important to establishing hydraulic retention times of inflows, which will determine retention or export of nutrients, affect mean depths, and affect development of thermal structure. Dillon (1975) suggested that relatively high internal phosphorus loading may be offset by reduced retention times or flushing. Based upon water quality conditions observed in the lake after impoundment, management strategies may be applied to improve water quality. For example, use of the selective withdrawal tower and judicious blending of water supply allocations in conjunction with Catoma Lake would allow some manipulation of nutrient retention and transport.

Operation of the reservoir may provide an opportunity to lessen the severity of potential problems associated with external nutrient loading by changing residence time and minimizing stratification, thereby reducing internal nutrient loading and increased concentrations of reduced metals. Additional analyses with BATHTUB would allow further assessment of management opportunities once likely operating conditions are known.

Finally, water quality monitoring in the reservoir after impoundment should be conducted to document changes in water quality, response to watershed management techniques, and for calibration and additional applications of the model.

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Walker, W.W. 1996. Simplified procedures for eutrophication assessment and prediction: User Manual, Instruction Report W-96-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

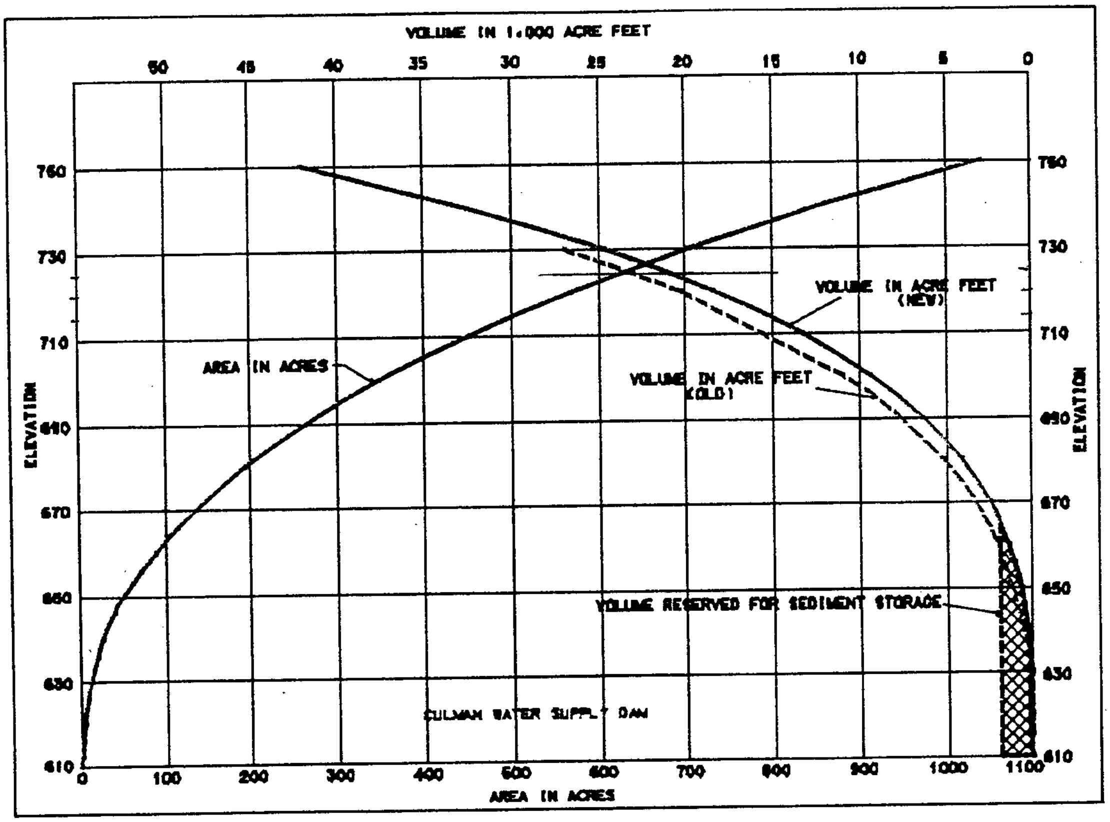


Figure 1. Area and capacity curve for the proposed project.

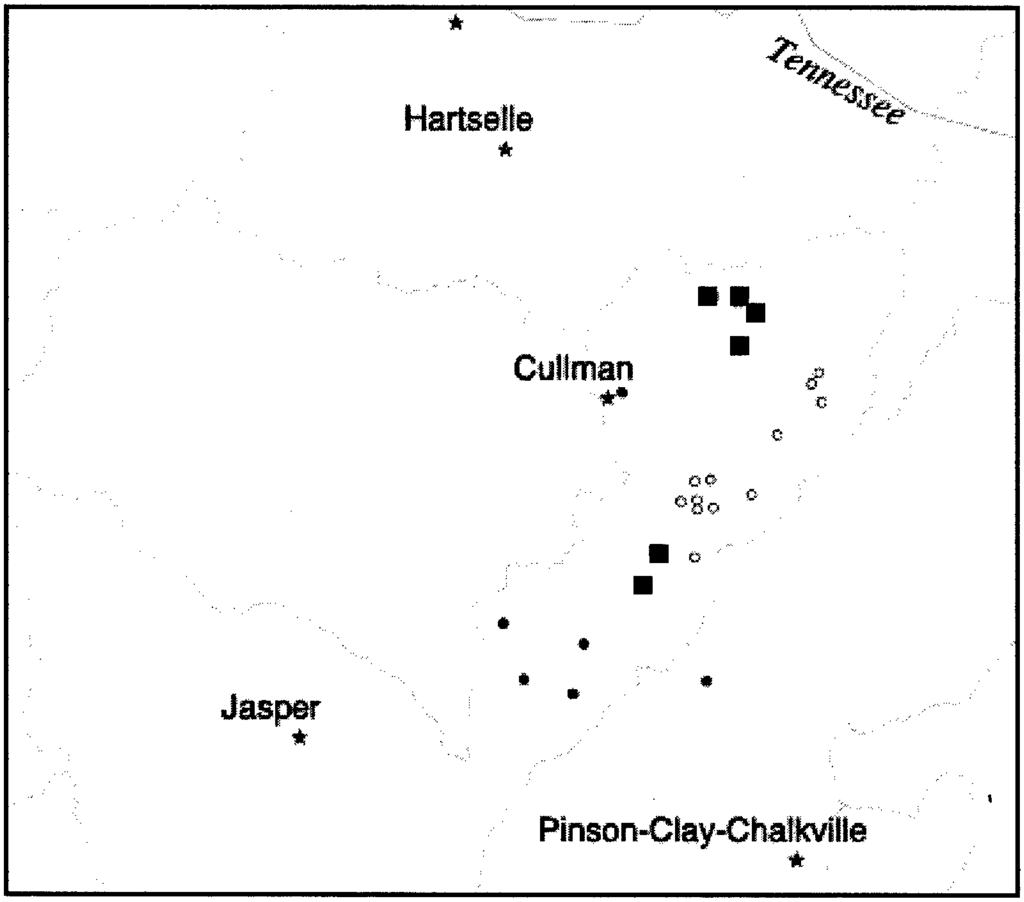


Figure 2. Station locations from STORET ○ (solid circles not included in data assessments) and ADEM ■.

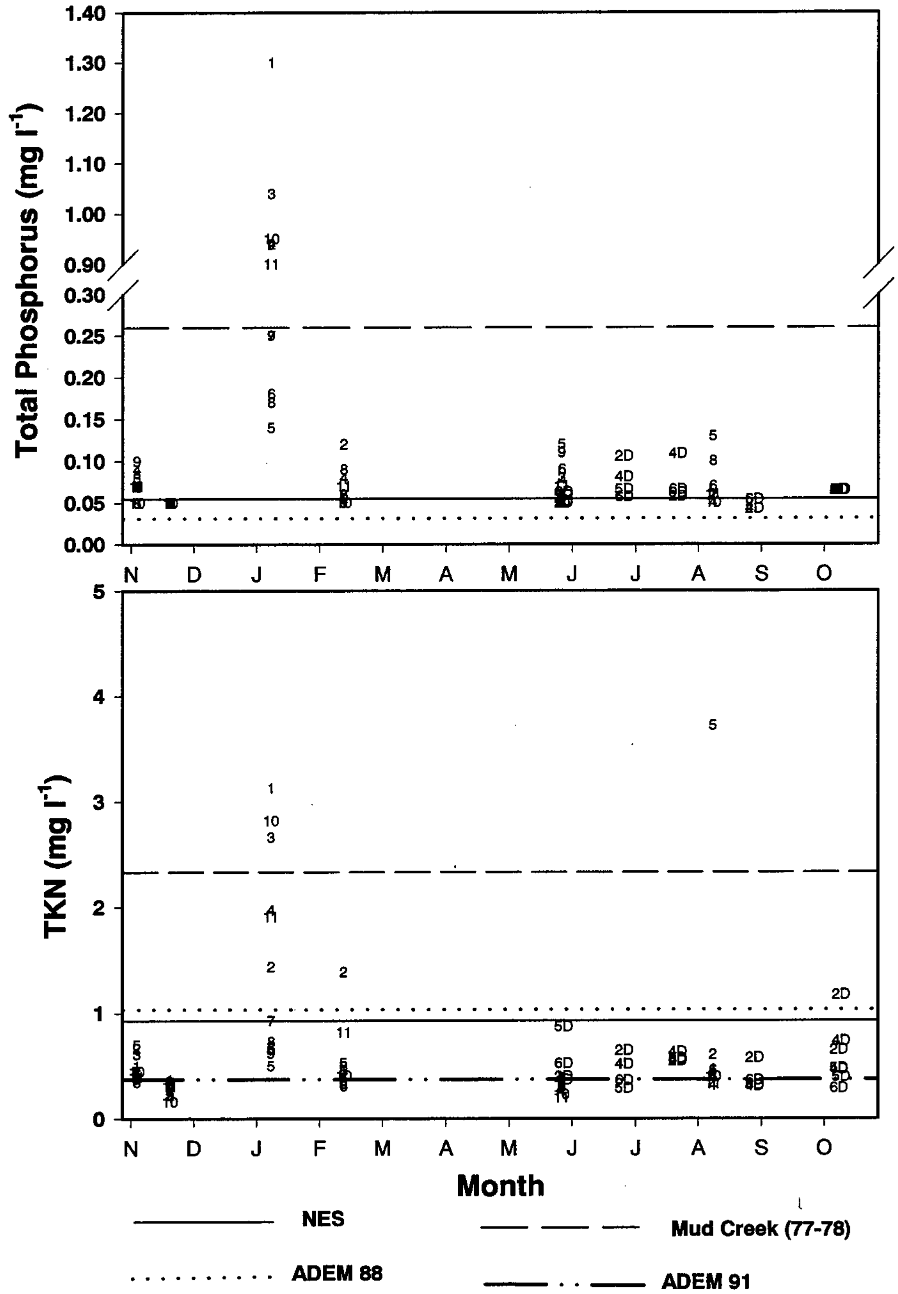


Figure 3. Total Phosphorus and Kjeldahl Nitrogen values from STORET, NES, ADEM, and TTL Inc. ADEM stations are represented by station numbers and TTL stations that corresponded to ADEM stations are denoted with a D next to the station number.

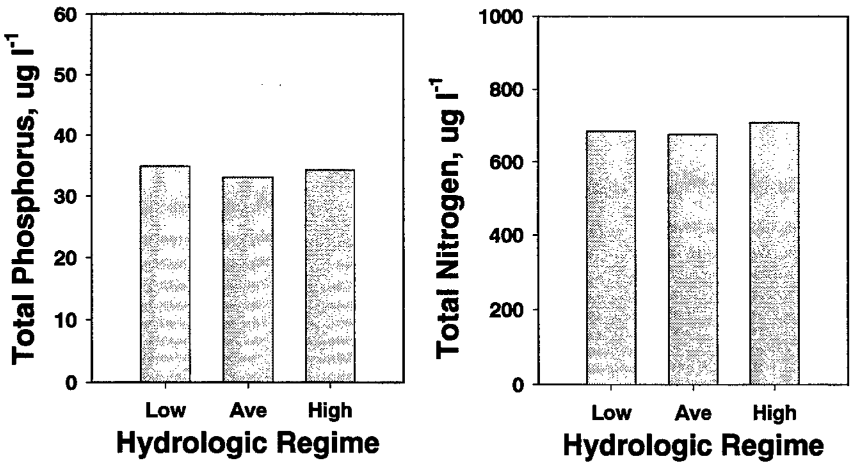


Figure 4. Predicted total phosphorus (left) and total nitrogen (right) concentrations for selected hydrologic regimes.

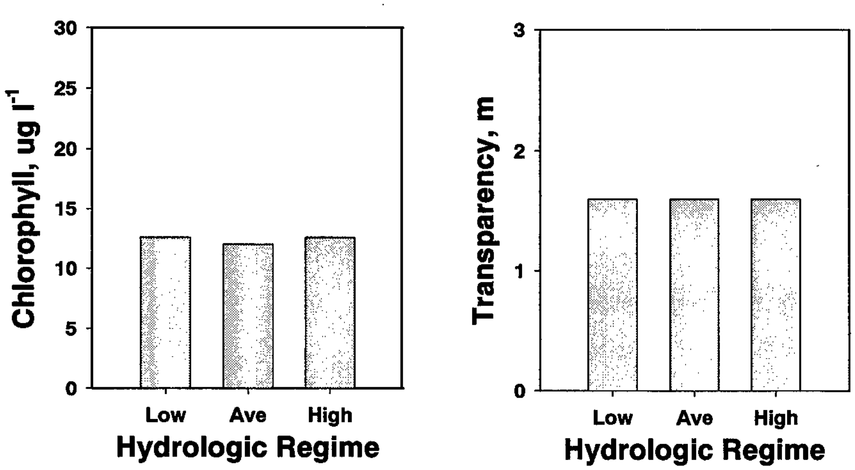


Figure 5. Predicted chlorophyll concentrations (left) and Secchi disk transparency (right) for selected hydrologic regimes.

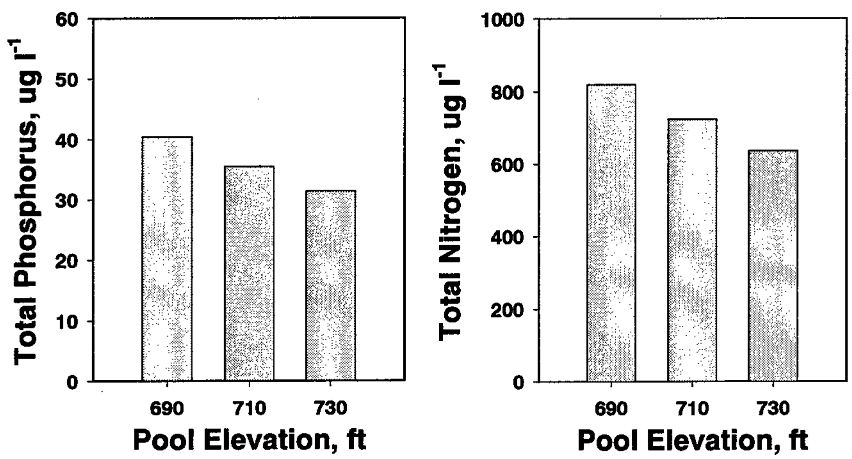


Figure 6. Predicted total phosphorus (left) and total nitrogen (right) concentrations for selected pool elevations. Inflow rate is 50 $ft^3$ $sec^{-1}$.

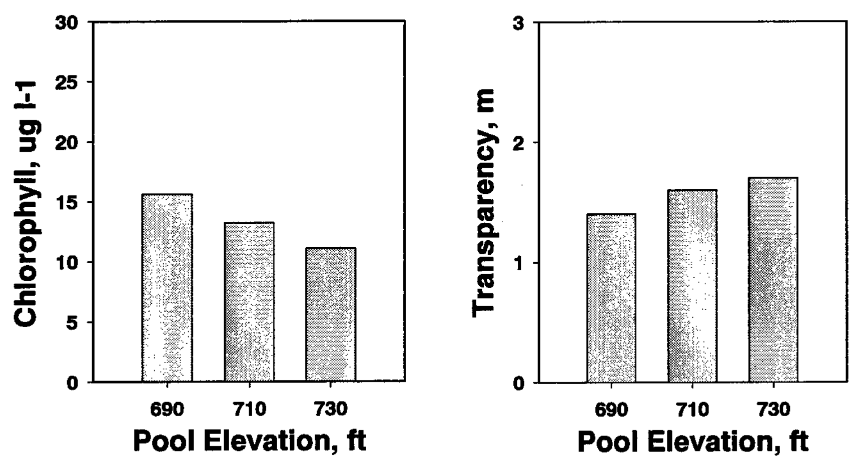


Figure 7. Predicted chlorophyll concentrations (left) and Secchi disk transparency (right) for selected pool elevations. Inflow rate is 50 $ft^3$ $sec^{-1}$.

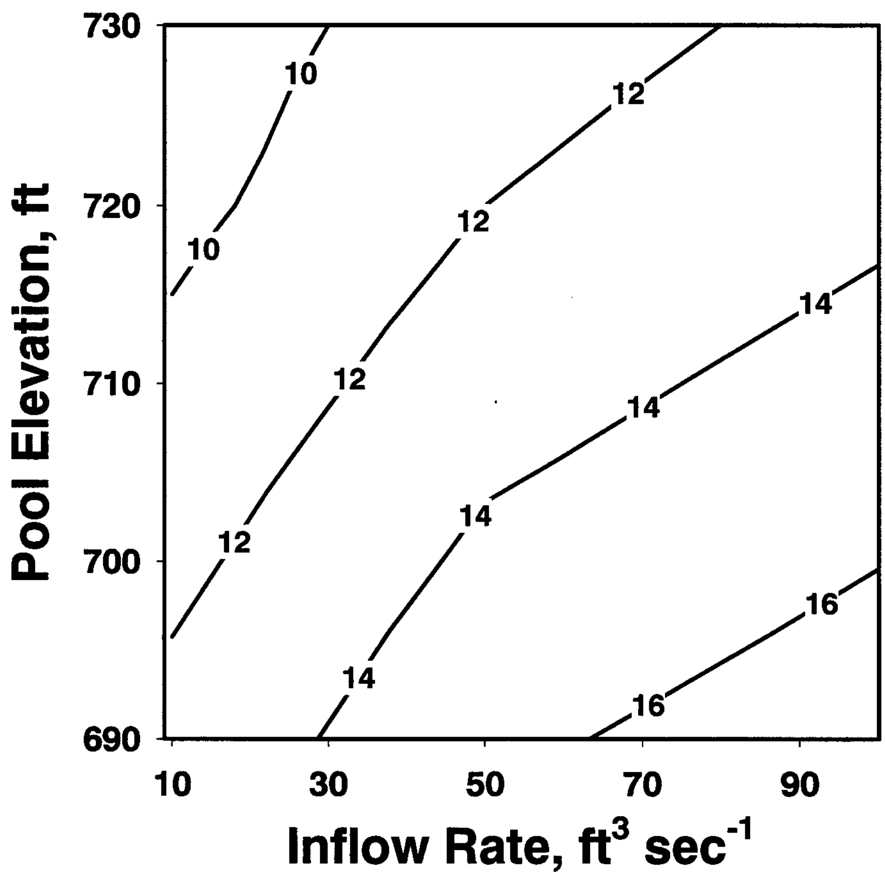


Figure 8. Predicted chlorophyll concentration (lines indicate concentrations in ug $l^{-1}$) as influenced by pool elevation and inflow rate.

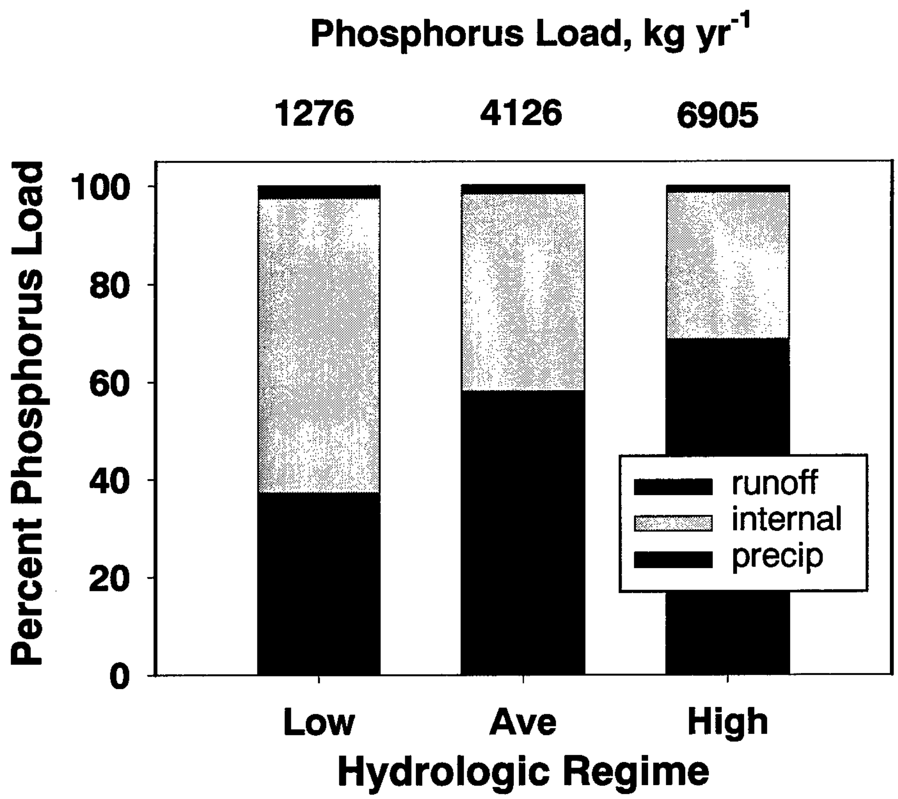


Figure 9. Relative contribution of phosphorus sources.

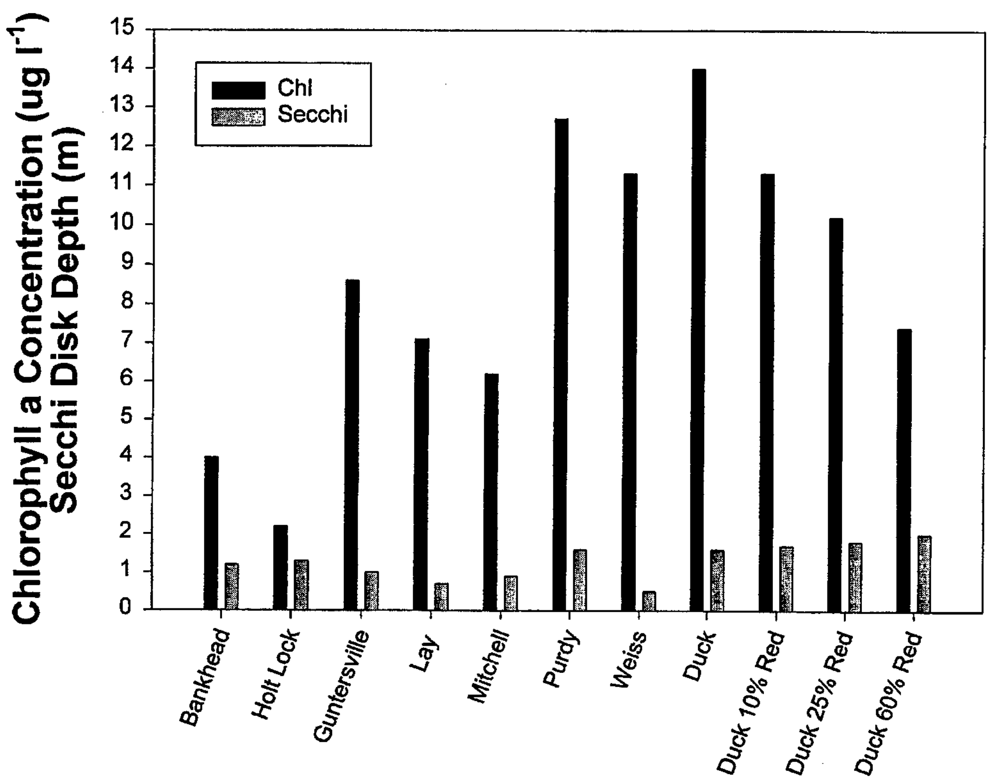


Figure 10. Comparisons of lake responses to other lakes and reductions in nutrient loads. Red = Reductions in nutrient loadings.

# Appendix A
# Input File for Scenario 1

MODEL OPTIONS:

| | |
|---|---|
| 1 CONSERVATIVE SUBSTANCE | 0 NOT COMPUTED |
| 2 PHOSPHORUS BALANCE | 3 2ND ORDER, FIXED |
| 3 NITROGEN BALANCE | 3 2ND ORDER, FIXED |
| 4 CHLOROPHYLL-A | 3 P, N, LOW-TURBIDITY |
| 5 SECCHI DEPTH | 1 VS. CHLA & TURBIDITY |
| 6 DISPERSION | 1 FISCHER-NUMERIC |
| 7 PHOSPHORUS CALIBRATION | 0 NONE |
| 8 NITROGEN CALIBRATION | 0 NONE |
| 9 ERROR ANALYSIS | 0 NOT COMPUTED |
| 10 AVAILABILITY FACTORS | 1 USE FOR MODEL 1 ONLY |
| 11 MASS-BALANCE TABLES | 1 USE ESTIMATED CONCS |

ATMOSPHERIC LOADS & AVAILABILITY FACTORS:

| | ATMOSPHERIC-LOADS | | AVAILABILITY |
|---|---|---|---|
| VARIABLE | KG/KM2-YR | CV | FACTOR |
| 1 CONSERV | .00 | .00 | .00 |
| 2 TOTAL P | 30.00 | .50 | 1.33 |
| 3 TOTAL N | 1000.00 | .50 | .59 |
| 4 ORTHO P | 15.00 | .50 | .33 |
| 5 INORG N | 500.00 | .50 | .79 |

GLOBAL INPUT VALUES:

| PARAMETER | MEAN | CV |
|---|---|---|
| PERIOD LENGTH YRS | 1.000 | .000 |
| PRECIPITATION M | 1.350 | .200 |
| EVAPORATION M | 1.040 | .300 |
| INCREASE IN STORAGE M | .000 | .000 |

TRIBUTARY DRAINAGE AREAS AND FLOWS:

| ID | TYPE | SEG NAME | DRAINAGE AREA KM2 | MEAN FLOW HM3/YR | CV OF MEAN FLOW |
|---|---|---|---|---|---|
| 1 | 5 | 1 Internal (Low) | .000 | .000 | .000 |
| 2 | 5 | 2 Internal (Low) | .000 | .000 | .000 |
| 3 | 5 | 3 Internal (Low) | .000 | .000 | .000 |
| 4 | 5 | 4 Internal (Low) | .000 | .000 | .000 |
| 5 | 2 | 1 Nonpoint Source | .000 | 48.001 | .000 |
| 6 | 2 | 2 Nonpoint Source | .000 | 48.001 | .000 |
| 7 | 2 | 3 Nonpoint Source | .000 | 48.001 | .000 |
| 8 | 2 | 4 Nonpoint Source | .000 | 48.001 | .000 |

TRIBUTARY CONCENTRATIONS (PPB): MEAN/CV

| ID | CONSERV | TOTAL P | TOTAL N | ORTHO P | INORG N |
|---|---|---|---|---|---|
| 1 | .0/ .00 | 2.0/ .00 | 20.0/ .00 | .0/ .00 | .0/ .00 |
| 2 | .0/ .00 | 2.0/ .00 | 20.0/ .00 | .0/ .00 | .0/ .00 |
| 3 | .0/ .00 | 2.0/ .00 | 20.0/ .00 | .0/ .00 | .0/ .00 |
| 4 | .0/ .00 | 2.0/ .00 | 20.0/ .00 | .0/ .00 | .0/ .00 |
| 5 | .0/ .00 | 50.0/ .00 | 980.0/ .00 | .0/ .00 | .0/ .00 |
| 6 | .0/ .00 | 50.0/ .00 | 980.0/ .00 | .0/ .00 | .0/ .00 |
| 7 | .0/ .00 | 50.0/ .00 | 980.0/ .00 | .0/ .00 | .0/ .00 |
| 8 | .0/ .00 | 50.0/ .00 | 980.0/ .00 | .0/ .00 | .0/ .00 |

MODEL SEGMENTS & CALIBRATION FACTORS:

| | | | | ----------- CALIBRATION FACTORS ----------- | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| SEG | OUTFLOW | GROUP | SEGMENT NAME | P SED | N SED | CHL-A | SECCHI | HOD | DISP |
| 1 | 0 | 1 | Cullman - E1690 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.000 |
| | | CV: | | .000 | .000 | .000 | .000 | .000 | .000 |
| 2 | 0 | 2 | Cullman - E1710 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.000 |
| | | CV: | | .000 | .000 | .000 | .000 | .000 | .000 |
| 3 | 0 | 3 | Cullman - E1720 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.000 |
| | | CV: | | .000 | .000 | .000 | .000 | .000 | .000 |
| 4 | 0 | 4 | Cullman - E1730 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.000 |
| | | CV: | | .000 | .000 | .000 | .000 | .000 | .000 |

SEGMENT MORPHOMETRY: MEAN/CV

| ID LABEL | LENGTH KM | AREA KM2 | ZMEAN M | ZMIX M | ZHYP M |
|---|---|---|---|---|---|
| 1 Cullman - E1690 | 10.00 | 1.0500 | 7.30 | 5.81/ .12 | .00/ .00 |
| 2 Cullman - E1710 | 10.00 | 1.8200 | 9.00 | 6.45/ .12 | .00/ .00 |
| 3 Cullman - E1720 | 10.00 | 2.2700 | 10.10 | 6.79/ .12 | .00/ .00 |
| 4 Cullman - E1730 | 10.00 | 2.8300 | 10.90 | 7.00/ .12 | .00/ .00 |

SEGMENT OBSERVED WATER QUALITY:

| SEG | TURBID | CONSER | TOTALP | TOTALN | CHL-A | SECCHI | ORG-N | TP-OP | HODV | MODV |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1/M | --- | MG/M3 | MG/M3 | MG/M3 | M | MG/M3 | MG/M3 | MG/M3-D | MG/M3-D |
| 1 MN: | .31 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 |
| CV: | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 2 MN: | .31 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 |
| CV: | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 3 MN: | .31 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 |
| CV: | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 4 MN: | .31 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 |
| CV: | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .0 |

NON-POINT-SOURCE WATERSHED AREAS (KM2):

| ID | COD | NAME | Nonpoint | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 2 | Nonpoint Source | 94.49 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 6 | 2 | Nonpoint Source | 94.49 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 7 | 2 | Nonpoint Source | 94.49 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 8 | 2 | Nonpoint Source | 94.49 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |

NON-POINT-SOURCE EXPORT COEFFICIENTS:

| IC | LAND USE | RUNOFF | CONSERV | TOTAL P | TOTAL N | ORTHO P | INORG N |
|---|---|---|---|---|---|---|---|
| | | M/YR | PPB | PPB | PPB | PPB | PPB |
| 1 | Nonpoint | .51 | .0 | 50.0 | 980.0 | .0 | .0 |
| | CV: | .00 | .00 | .00 | .00 | .00 | .00 |
| 2 | | .00 | .0 | .0 | .0 | .0 | .0 |
| | CV: | .00 | .00 | .00 | .00 | .00 | .00 |
| 3 | | .00 | .0 | .0 | .0 | .0 | .0 |
| | CV: | .00 | .00 | .00 | .00 | .00 | .00 |
| 4 | | .00 | .0 | .0 | .0 | .0 | .0 |
| | CV: | .00 | .00 | .00 | .00 | .00 | .00 |
| 5 | | .00 | .0 | .0 | .0 | .0 | .0 |
| | CV: | .00 | .00 | .00 | .00 | .00 | .00 |
| 6 | | .00 | .0 | .0 | .0 | .0 | .0 |
| | CV: | .00 | .00 | .00 | .00 | .00 | .00 |
| 7 | | .00 | .0 | .0 | .0 | .0 | .0 |
| | CV: | .00 | .00 | .00 | .00 | .00 | .00 |
| 8 | | .00 | .0 | .0 | .0 | .0 | .0 |
| | CV: | .00 | .00 | .00 | .00 | .00 | .00 |

MODEL COEFFICIENTS:

| COEFFICIENT | MEAN | CV |
|---|---|---|
| DISPERSION FACTO | 1.000 | .70 |
| P DECAY RATE | 1.000 | .45 |
| N DECAY RATE | 1.000 | .55 |
| CHL-A MODEL | 1.000 | .26 |
| SECCHI MODEL | 1.000 | .10 |
| ORGANIC N MODEL | 1.000 | .12 |
| TP-OP MODEL | 1.000 | .15 |

| | | |
|---|---|---|
| HODV MODEL | 1.000 | .15 |
| MODV MODEL | 1.000 | .22 |
| BETA M2/MG | .025 | .00 |
| MINIMUM QS | 4.000 | .00 |
| FLUSHING EFFECT | 1.000 | .00 |
| CHLOROPHYLL-A CV | .620 | .00 |

CASE NOTES:
Loading based on NES NPS and internal loading (low rate)
Runoff rate set to regional average (equivalent to ca. 50 $ft^3$ $sec^{-1}$)
Each segment set to different pool elevation (690-730ft)

# REPORT DOCUMENTATION PAGE

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**13. ABSTRACT *(Maximum 200 words)***

Potential water quality problems related to agricultural eutrophication at a proposed water supply reservoir on the Duck River near Cullman, AL, were assessed with BATHTUB, an empirical model that predicts chlorophyll and transparency values. Since the reservoir has not yet been constructed and little information on nutrient loading was available, scenarios were developed with estimated data and various flow regimes. Evaluation of available data, data collected in the area during the National Eutrophication Survey (NES) conducted by the U.S. Environmental Protection Agency, and data from STORET provided a reasonable estimate for phosphorus and nitrogen concentrations. In anticipation of inflow water quality improvements associated with implementation of best management practices, scenarios were also conducted with nutrient reductions of 10, 25, and 60 percent of the estimated loading. Results indicated that reservoir water quality may be classified as mesoeutrophic or eutrophic depending on nutrient loading and hydraulic residence time. Water quality will be sensitive to the hydrology and operation with a tendency toward higher clorophyll concentrations and decreased transparency associated with increased residence time. Implementation of best management practices in the watershed, resulting in decreased nutrient loading, will improve water quality and result in conditions similar to those of other area lakes. Operations using the selective

(Continued)

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| Eutrophication assessment | Phosphorus | |
| Loading | Reservoir | |

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withdrawal capabilities of the multilevel intake tower and water allocations associated with a second water supply reservoir can also be used to improve water quality.